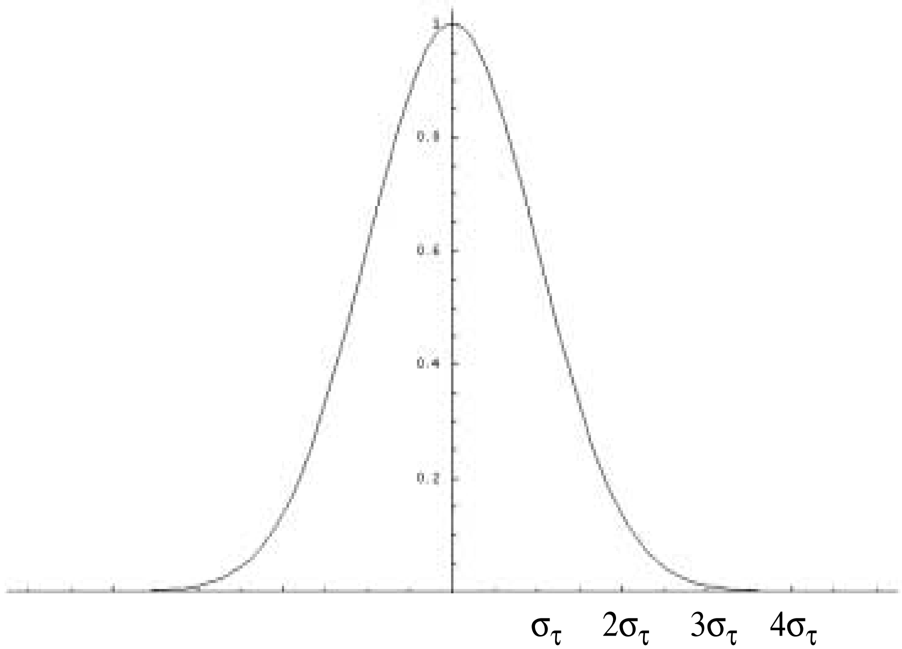
Time

Bunch structure

Time Scales

Instrumentation

Bunch Length σ_τ



Source Type	σ_τ
Storage Rings	10's of picoseconds
UV SASE FEL*	< 1 ps
X-ray FEL*	10's of femtoseconds
Energy recovery linacs*	100 fs - few ps

* Linac-based sources generate very non-Gaussian bunches

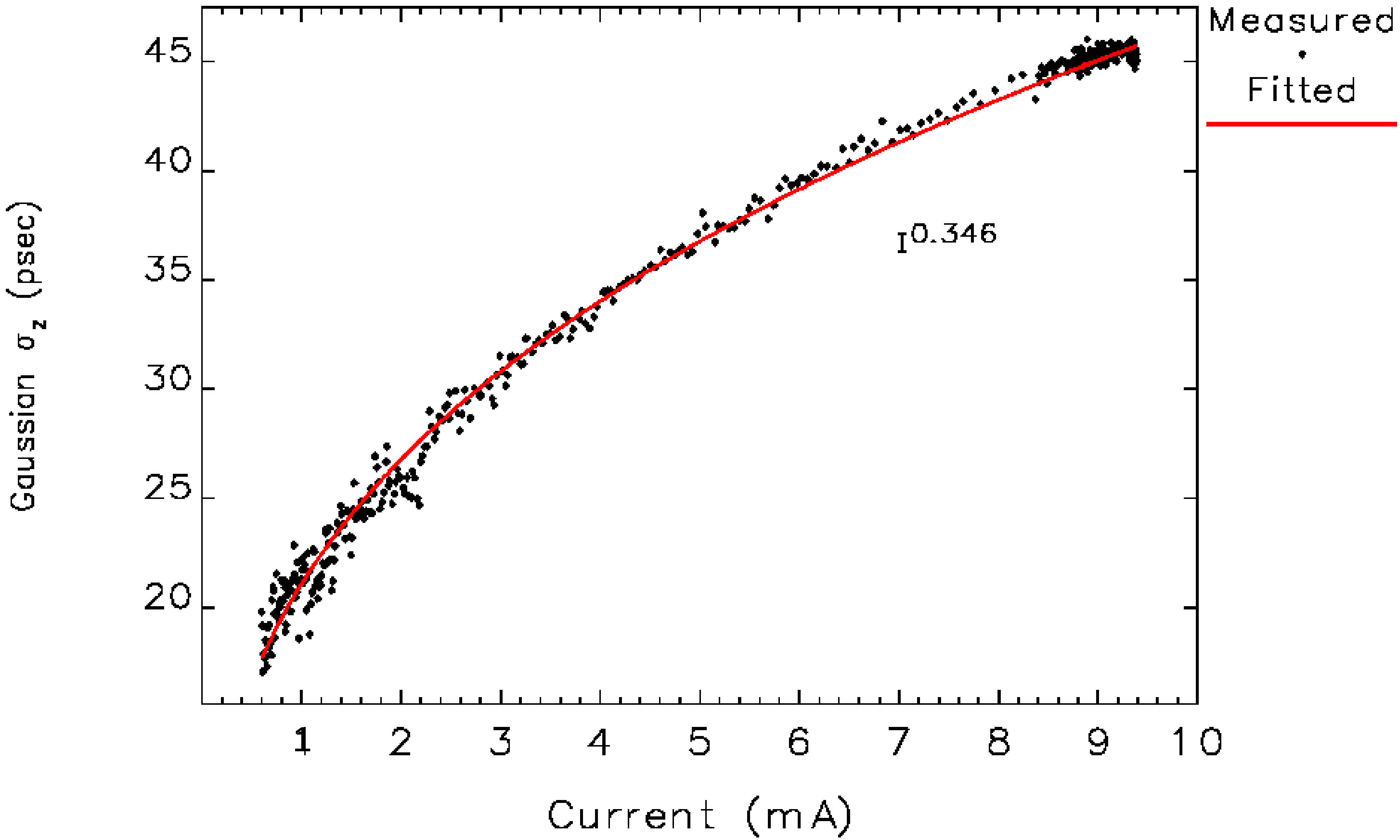
Equilibrium Zero-current bunch length - storage ring

$$\sigma_\tau = \{ 2 \pi \alpha h E / \omega_{RF}^2 \cos \phi_s e V_{RF} \}^{1/2} \sigma_E$$

α = momentum compaction
h = harmonic number = f_{rf} / f_{rev}
E = Energy
$\omega_{RF} = 2 \pi f_{rf}$

ϕ_s = Synchronous phase
V_{RF} = RF voltage
σ_E = Energy spread,
(proportional to energy)

APS Bunch Length Data



Time Scales for Modern Storage Ring - Based Light Sources

	APS	**SPEAR-3**	**SRC - Aladdin**	**NSLS UV ring**
Beam Energy	7 GeV	3 GeV	1.0 GeV	750 MeV
RF Period	2.84 ns	2.10 ns	19.8 ns	18.9 ns
Circumference L	1104 meters	234 meters	88.9 meters	51 meters
Revolution period T_{rev}	3683 ns	781 ns	297 ns	170 ns
Harmonic number h	$1296 = 2^4\ 3^4$	372	15	9
RF Frequency f_{RF}	352 MHz	476 MHz	50.582 MHz	53 MHz
Revolution freq. f_{rev}	271 kHz	1.28 MHz	3.37 MHz	5.88 MHz
Bunch Length σ_τ	35 ps	19 ps	479 ps	162 - 500 ps

$f_{rev} = c / L$

$T_{rev} = L / c$

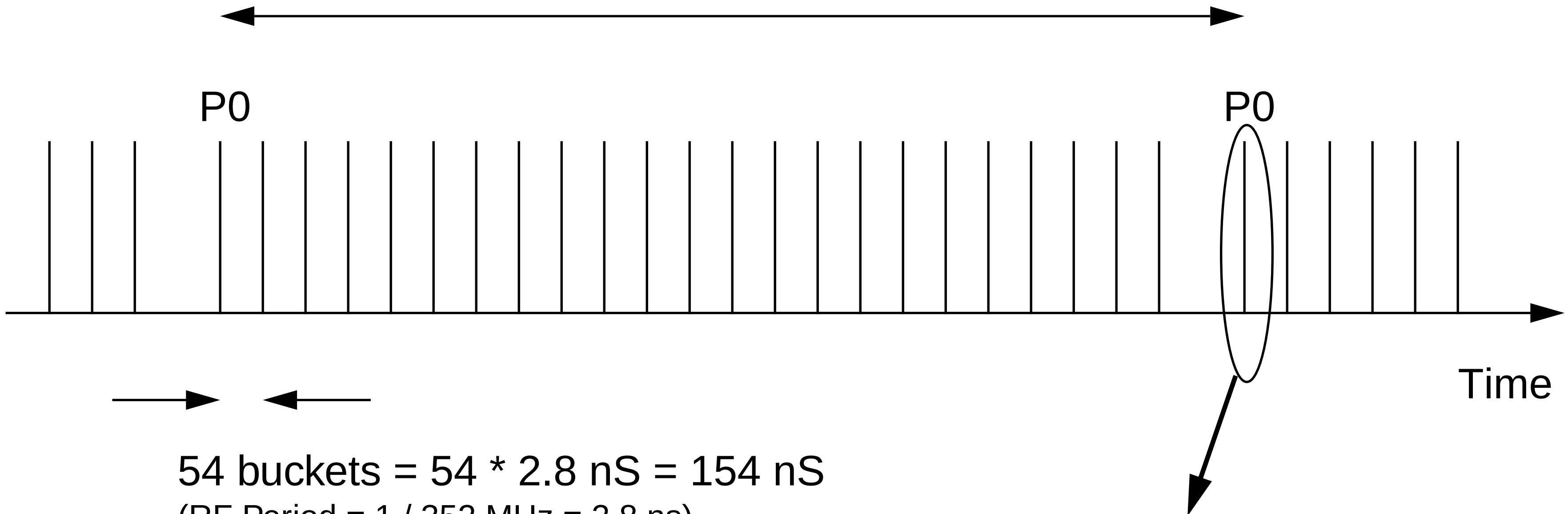
$c = 2.9979e8$ m / s

h = Harmonic number
= Maximum number of bunches
= f_{RF} / f_{rev}

RF Period = $1 / f_{RF}$
= Minimum bunch spacing

APS 24 -1 Singlets Fill Pattern

Revolution period = 3.68 microseconds = 1296 buckets



54 buckets = 54 * 2.8 nS = 154 nS
(RF Period = 1 / 352 MHz = 2.8 ns)

T_{rev} / σ_{τ} = 100,000

Comparison of Time Scales for Different Light Source Technologies

	APS	LCLS	TESLA	ERL
Beam Energy	7 GeV	15 Gev	25 GeV	5.3 GeV
RF Period	2841 ps	350 ps	769 ps	769 ps
Pulse Rep. Period	11 - 154 ns	8.3 milliseconds	17.7 μs**	769 ps
Bunch Length FWHM	73 ps	230 femtosec.	90 femtosec.	300 femtosec.
RF Frequency	352 MHz	2856 MHz	1300 MHz*	1300 MHz*
Pulse Rep. Frequency	6.5 - 88 MHz	120 Hz	56575	1300 MHz
Charge / pulse	14 nC	1 nC	1 nC	8 - 77 pC
Average Current	100 mA	72 nanoAmps	63 microAmps	10 - 100 mA

* Superconducting RF
** 11315 buckets * 93 nsec * 1 nC Bunch Trains * 5 Hz

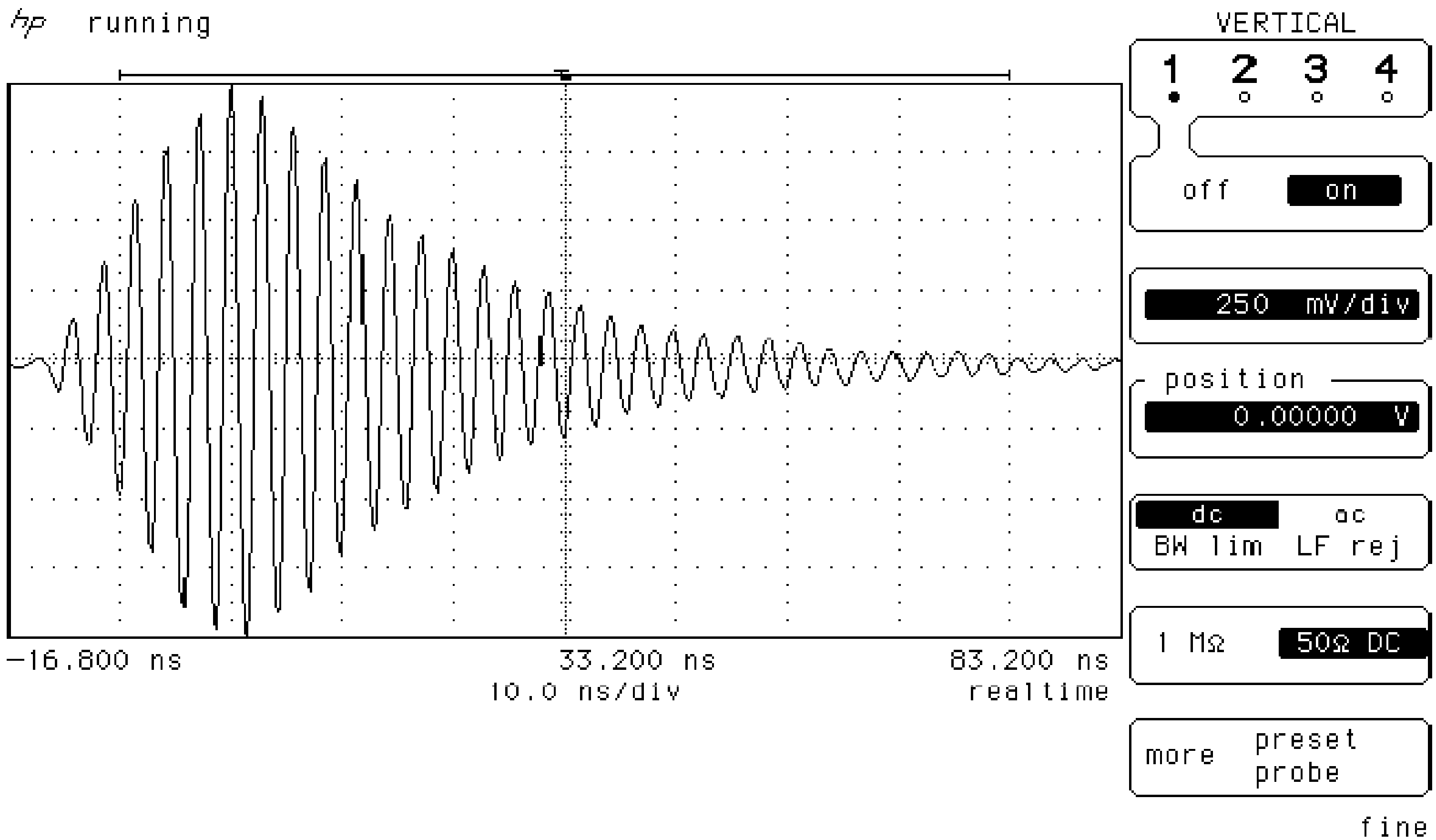
http://erl.chess.cornell.edu/papers/ERL_Study.pdf

Oscilloscopes

Specifications

Analog Bandwidth up to > 6 GHz
Sample Rate up to 20 GS / sec
Sub-ps jitter, rise time
Common PC / windows operating systems
Most often use 8-bit resolution
Some units provide convenient interface to network.

Cavity filters with 6 bunches @ 1.67 ma/bunch sum input



Transient Digitizers

Trade off speed for resolution - 14 vs. 8 bits for typical fast oscillo-scope

Usually requires additional digital signal processor plus competent programmer

Special-purpose digital radios available with a lot of on-board firmware.

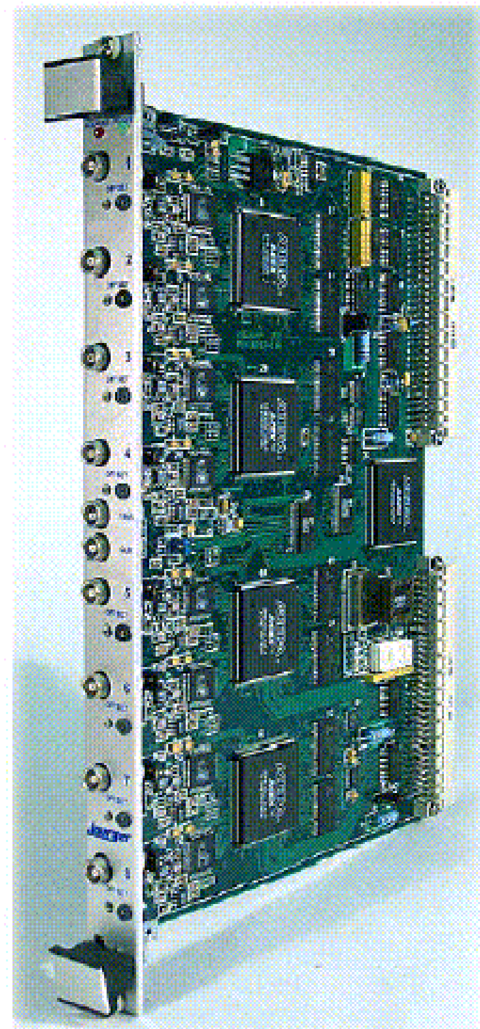
Joerger ENTERPRISES, INC.

MODEL VTR8014

EIGHT CHANNEL, 80 MHZ, 14 BIT "VME" ANALOG DIGITIZER WITH OSCILLOSCOPE CHARACTERISTICS

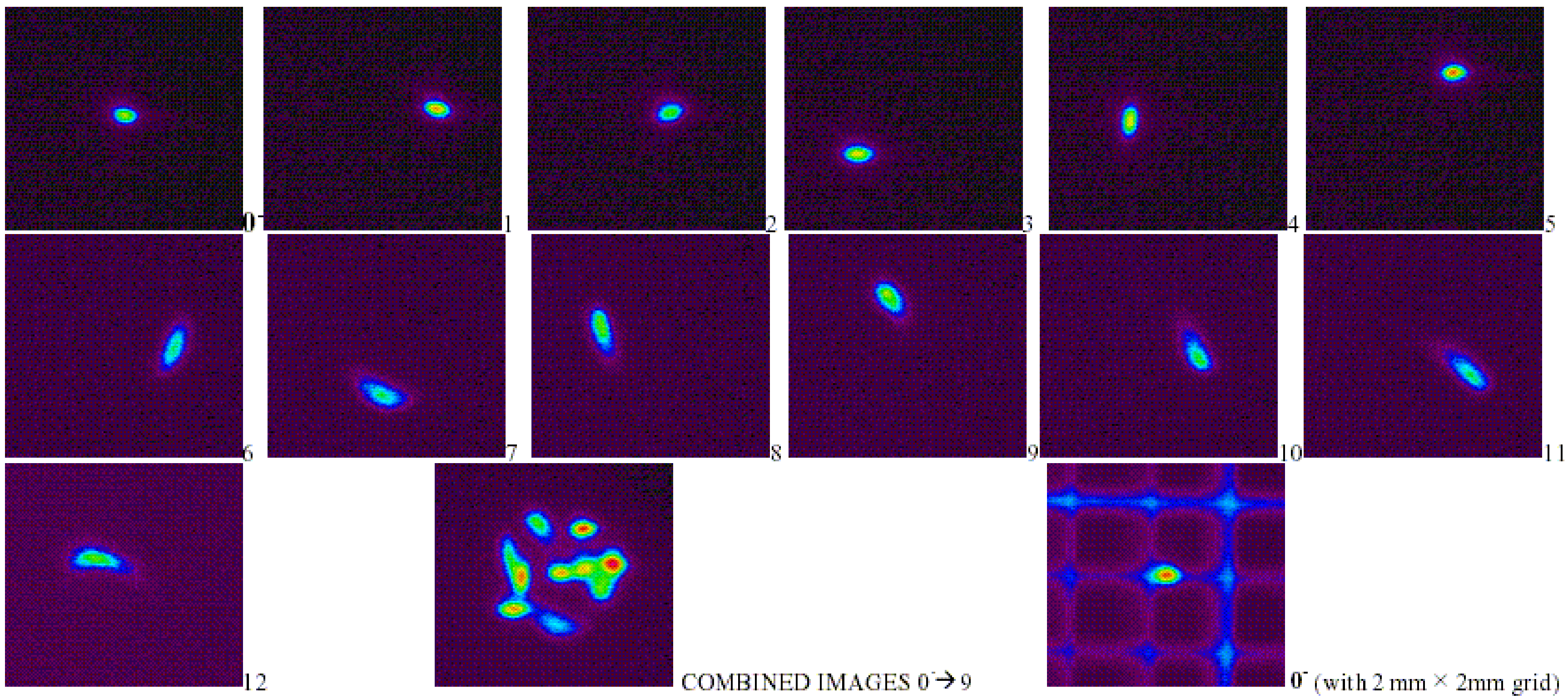
FEATURES:

- 1, 2, 4 OR 8 INDIVIDUAL CHANNELS
- 80 MHZ CLOCK SPEED
- 14 BIT RESOLUTION PLUS SIGNAL AVERAGING FOR IMPROVED SNR
- ***"OSCILLOSCOPE"*** TYPE INPUTS FEATURING:
  - HIGH INPUT IMPEDANCE, 10 MΩ's
  - FULL SCALE OFFSET CONTROL
  - SINGLE ENDED OR DIFFERENTIAL INPUTS
  - WIDE INPUT BANDWIDTH FOR GOOD WAVEFORM TRACKING
- 256K SAMPLES OF SRAM PER CHANNEL, 2M SAMPLES TOTAL
- CHANNELS CAN BE READ AT ANY TIME PROVIDING:
  - SIGNAL MONITORING
  - OFFSET ADJUST AND TEST
  - GAIN TESTING
- READ OUT OF MODULE TYPE AND IT'S SERIAL NUMBER
- RECORDING MODES:
  - POST TRIGGER
  - MULTIPLE POST TRIGGER
  - PRE/POST TRIGGER
  - MULTIPLE PRE/POST TRIGGER
- GLOBAL COMMANDS FOR MULTIPLE MODULE OPERATION
- ALL TRIGGER ADDRESSES STORED
- REAL TIME TRIGGER ARRIVAL STORED
- TRIGGER COUNTER PROVIDED
- NUMBER OF EVENTS REGISTER
- INDIVIDUAL FILTERING OF EACH CHANNELS POWER AND GROUND
- HIGH NOISE IMMUNITY AND LOW CHANNEL CROSSTALK



Injection Transient

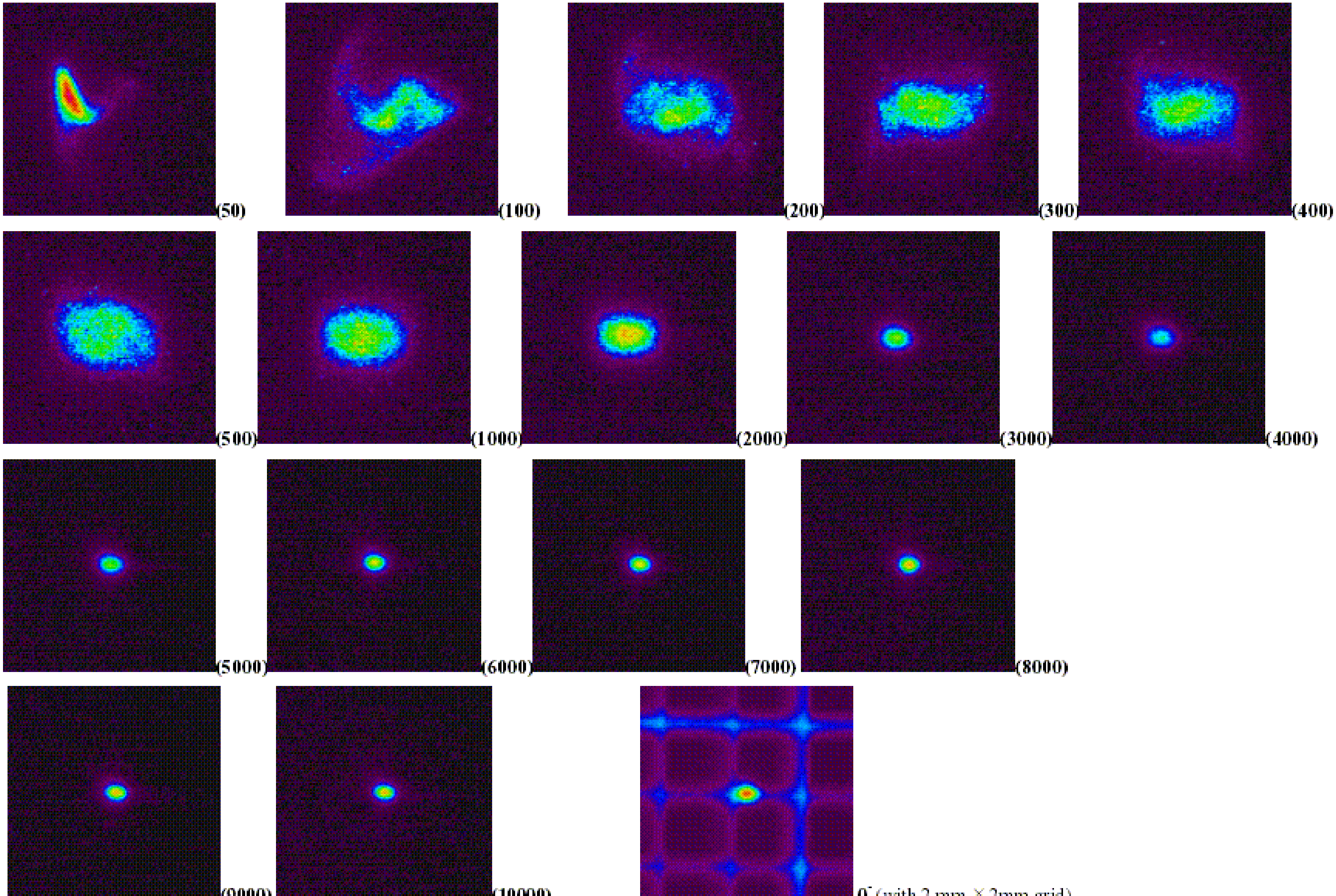
Gated camera single turn images (1/19/98)



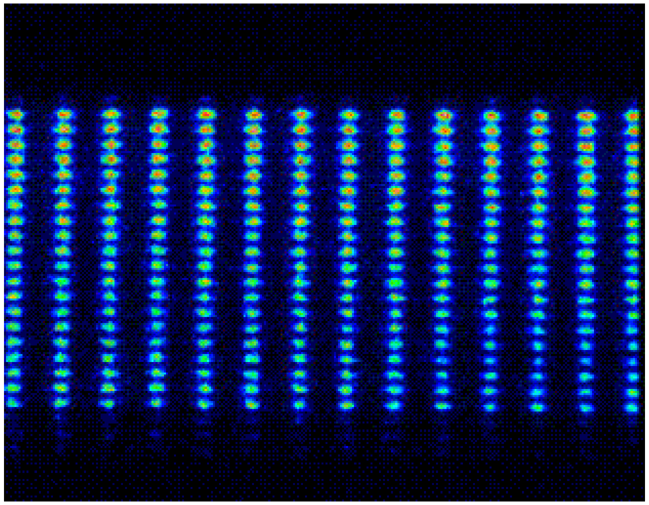
Turn after injection

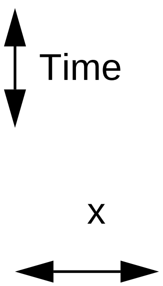
Transverse Damping

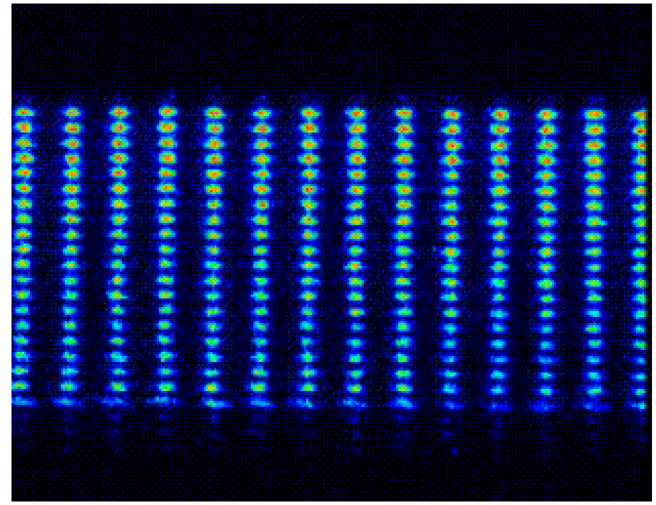
Gated camera single turn images (1/19/98)



Streak Camera Image of Bunch Train Instability

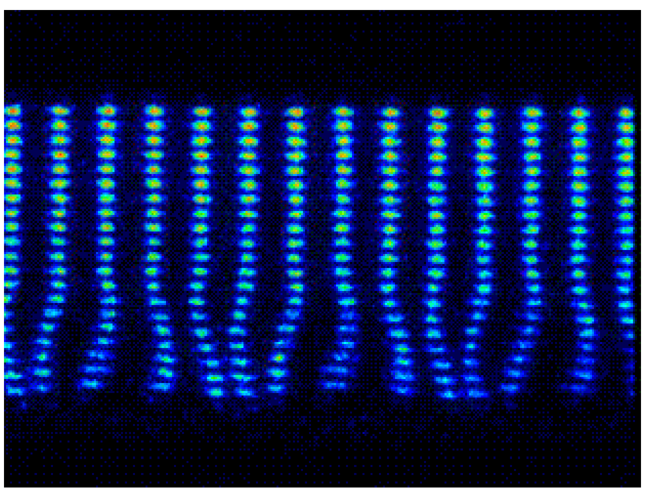


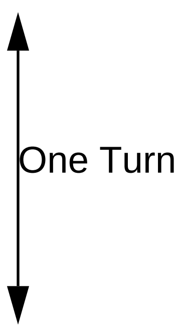


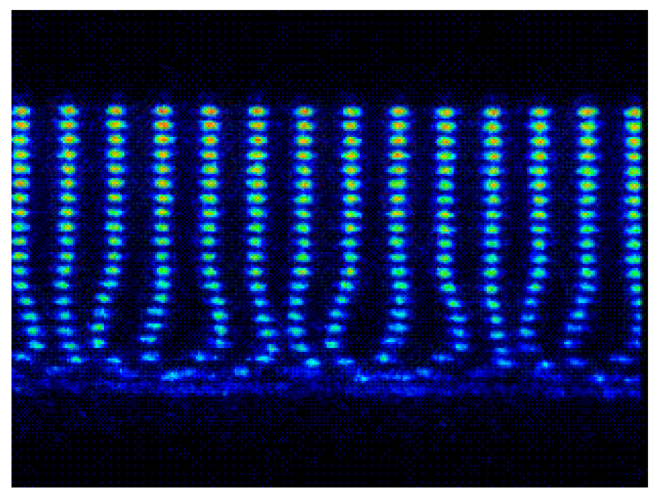


(A) $\xi_x = \xi_0$ (Chromaticity)

(B) $\xi_x = \xi_0 - 3.0$







(C) $\xi_x = \xi_0 - 4.8$

(D) $\xi_x = \xi_0 - 5.2$